Mike Halling
1/22/92
PBAR NOTE #519

Measurement of Transverse Beam Size in Accumulator as a Function of Momenta During Stacking

ABSTRACT

The horizontal and vertical emittance as a function of momentum was measured in the accumulator while stacking with a small stack. The data suggests that the transverse emittance of the beam is blown up between the injection orbit and the stacking orbit. The technique shows promise, and should be repeated with a large stack to measure the emittance in the accumulator at a time when we have large losses.

MOTIVATION

We often observe large loss of beam in the accumulator during stacking, especially with large stacks. We have excellent diagnostics that show us what is happening in longitudinal phase space while stacking, and we have transverse emittance measurements of the core; but there are many other physical quantities necessary to fully describe the beam in the accumulator. We often experience periods of poor stacking efficiency with both of these diagnostics showing good operating conditions, which suggests that the beam loss is in an area insensitive to these diagnostics. This report shows the first measurement to my knowledge of the emittance of beam at momenta different than the core while stacking.

TECHNIQUE

These measurements were made by scraping the beam away with the horizontal and vertical scrapers. Since the measurements took as much as an hour to complete all accumulator cooling systems were turned off for the duration, as well as ARF1 and the injection kicker. The beam shakers were also off but the dampers were on. A spectrum analyzer was used to measure the fraction of particles remaining at each scraper position. Since the measurement occurred over many minutes with all RF and cooling off, and occurred at low intensity, it is unlikely that coherent signals contaminated the spectrum analyzer measurement of the particle density. It is also apparent from the raw data that longitudinal diffusion was small at the low stack size used in the measurement.

The position of the closed orbit was measured by moving the scraper in small .3-.5 mm steps until no beam was visible on the spectrum analyzer. For the horizontal measurement this process was performed both with beam on the core orbit and beam moved over to the injection orbit with ARF3. The change in the closed orbit position from core to injection orbit is about .5 mm, in good agreement with independent results using the BPM system. For the vertical measurement the closed orbit was measured at three locations, the core orbit, the injection orbit, and the stacking orbit. The change in the closed orbit location from core to injection orbit was 2 mm, also in good agreement with recent BPM data. The dispersion in each dimension was assumed to be linear in the calculation of the emittance below.

BEAM PREPARATION

The data shown below were taken on 1/13/92 during the first four hours of stacking. Due to the short amount of time and pbars allocated to this measurement the emittance was measured with stacks of about .5 ma with a cycle time of 2.4 seconds. This is before a proper core has formed in the accumulator. In addition, the main ring was delivering wider bunches than normal, and the source was not completely tuned up since it had just been turned on after reverse proton studies. ARF1, which often shows bad behavior, was certified at the time as being in working condition. Due to these limitations this measurement should be considered a proof of technique rather than the absolute last word on what is happening in the source with large stacks.

The procedure of obtaining a beam sample was as follows. After about 20 minutes of uninterrupted stacking the three core cooling systems were turned off. ARF1 was then turned off using A:R1APSV, and roughly 4 seconds later the stack tail system was turned off. For some reason I also opened the injection shutter at this point. ARF1 was then turned on/off for one beam pulse in the middle of the supercycle to trap beam on the stacking orbit. A:IKIK was then turned off after a pulse in the middle of the supercycle to trap a fresh pulse on the injection orbit.

THE DATA

Figure 1 shows two spectrum analyzer traces, one just after stacking was stopped and one with the A:RJ500 at 16.06 mm. The closed orbit location is at about 11.5 mm. An averaging function similar to the video bandwidth function has been applied to the raw spectrum analyzer data to smooth out small fluctuations. If the emittance were the same at all momenta the vertical distance between the traces would be constant. The ratio of the power levels between the two traces gives a measurement of the fraction of particles scraped away between the two measurements. Making the assumption that the particle density in transverse phase space is gaussian I use a lookup table to calculate, SIGMAS, the number of sigma from the mean of a gaussian distribution such that the integral for 0-SIGMAS is consistent with the measurement with the scraper. For instance, if I cut away 5% of the beam then SIGMAS=2. If I cut 10% then SIGMAS=1.6. From the position of the scraper I calculate the area in phase space contained between the scraper location and the closed orbit, PHSPC=(16.06-11.5)**2/14 in the above example. The 95% emittance is then equal to 2*PHSPC/SIGMAS.

Figure 2 shows the measured horizontal emittance for scraper positions of 18.24 mm, 17.49 mm, 16.74 mm, 16.06 mm, 15.35 mm and 14.71 mm. Momenta with small amounts of beam have an emittance of zero in the plot. The fact that the curves lie on top of each other demonstrates that the particle distribution is gaussian and centered in phase space. The measured emittance of 6 pi at the injection orbit is larger than that measured in the debuncher in an earlier measurement. Figure 3 is simply a superposition of Figures 1 and 2.

Figure 4 shows the raw spectrum analyzer plots taken with A:TJ307 out, at 5.57 mm, 2.71 mm, 1.47 mm, and -1.01 mm. The central orbit is at about -4.2 mm at the injection orbit and -2.2 mm near the core. It is obvious from the plots that the distribution of particles in phase space is different between the stacking orbit and the injection orbit. Figure 5 shows the calculated emittance distributions for the scraper at 7.23 mm, 6.48 mm, 5.57 mm, 5.01 mm, and 4.18 mm. All the curves again fall on top of each other verifying that in this range the gaussian approximation is good. There is an apparent blowup of the emittance on the stacking orbit, which leaves the emittance on the stacking orbit dangerously close to the aperture limit. Even more ominous is the emittance calculated using the spectra taken with the scraper in the 3.28 mm, 2.71 mm, and 2.11 mm positions, shown in Figure 6. The fact that the calculated emittance is larger than that in Figure 5 indicates that the beam does not have a gaussian distribution in phase space, but rather has a hollow distribution.

By calculating the difference between the successive spectra and dividing by the change in phase space area between each measurement I obtain the phase space density distribution of particles on the injection and stacking orbits, shown in Figures 7 and 8. Hand drawn curves are shown in Figures 7 and 8 to guide the eye. On the injection orbit the distribution is centered about the central orbit and looks somewhat gaussian. On the stacking orbit the distribution is clearly depleted near the central orbit.

DISCUSSION OF RESULTS

The beam on the injection orbit is about 6 pi in each dimension. This is much higher than the emmittances of 3-4.5 pi horizontal and 3-3.5 pi vertical measured in the debuncher just before extraction. The data also shows an obvious increase in the effective emittance as the beam moves from the injection orbit to the stacking orbit, then a decrease as the beam moves towards the core. This effect is more pronounced in the vertical dimension than the horizontal dimension. It is remotely possible that ARF1 causes this blowup, after which the beam is cooled by the core cooling system. My simple calculation of the time delay of the 4-8 GHZ cooling system shows that it cools down to about 79.241/126 MHZ.

Another piece of information that might be useful in explaining this effect is is the fact that there is very strong coupling in the accumulator. Figures 9-12 show measurements of the accumulator tunes taken on the same day as the data described above. There is very strong coupling near the central orbit, and it is impossible to identify the horizontal from the vertical tune at the injection orbit. It is altogether possible that the tunes were crossed at this time, as they were in two earlier measurements shown in Figures 13 and 14. The effects of coupling on emittance measurements will be the subject of another PBAR note.

FUTURE MEASUREMENTS

This technique appears to work, and shows promise of adding to our knowledge of stacking losses. Unfortunately, the emittance in the accumulator with 0.5 ma stacks is not a very interesting thing to measure. What is interesting is the emittance with large stacks, when as many as 50% of the incoming pbars are lost somewhere in the accumulator. This measurement should be repeated with a large stack at a time when we are experiencing large losses. Since we now know the position of the closed orbit it is only necessary to scrape off about 5% of the pbars in each dimension to make the measurement.

The present scraper system makes this measurement very awkward, time consuming, and dangerous to make on a regular basis. I am convinced that these measurements will be useful in the future, and therefore propose that we build at least one scraper in each dimension that reliably moves to the position it is told with one command with no danger of overshoot.

Figure 1

CONSOLE LOCATION 43, 22-JAN-1992 14:27
Pbar SA Plot

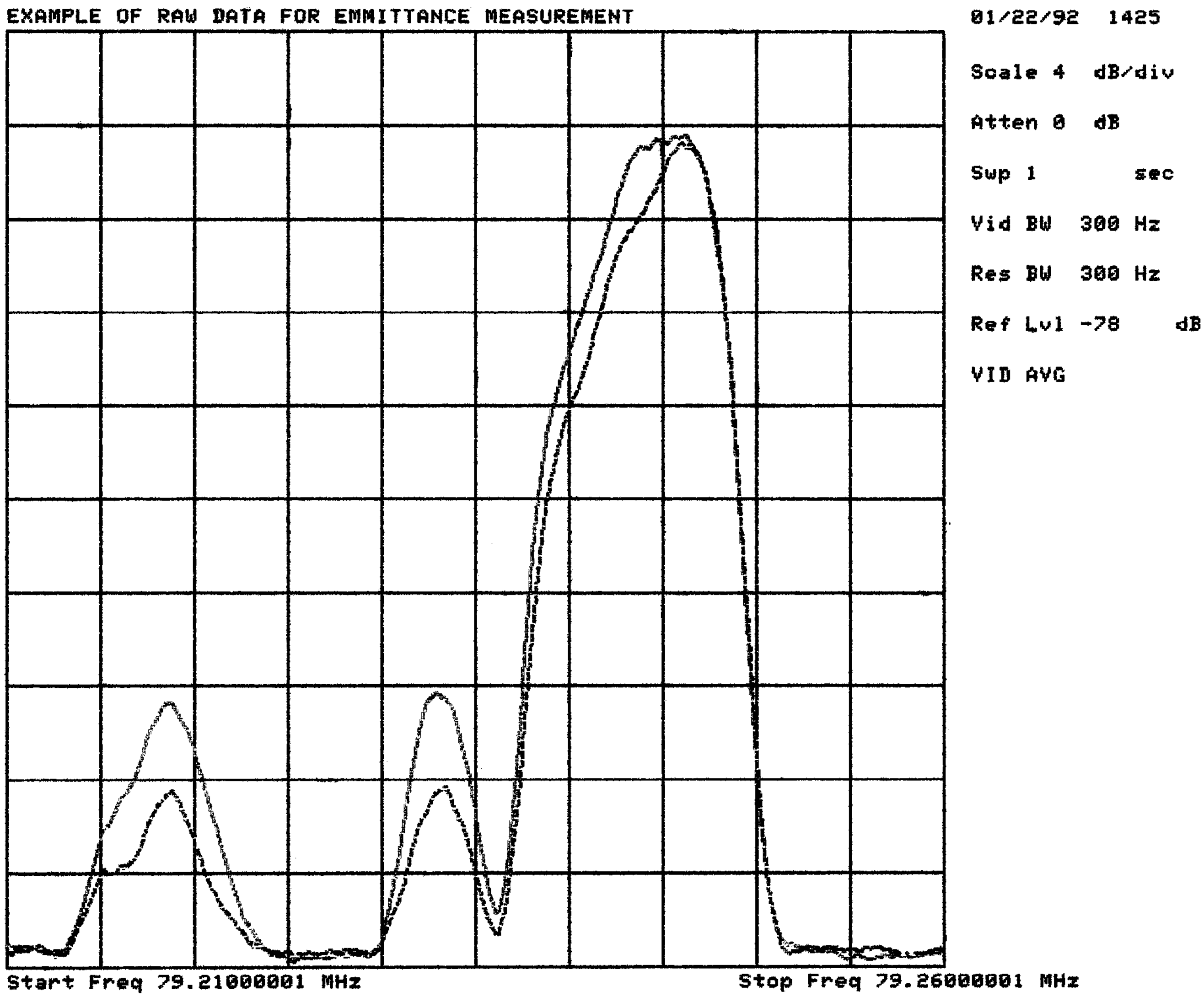


Figure 2

CONSOLE LOCATION 43, 22-JAN-1992 14:24
Pbar SA Plot

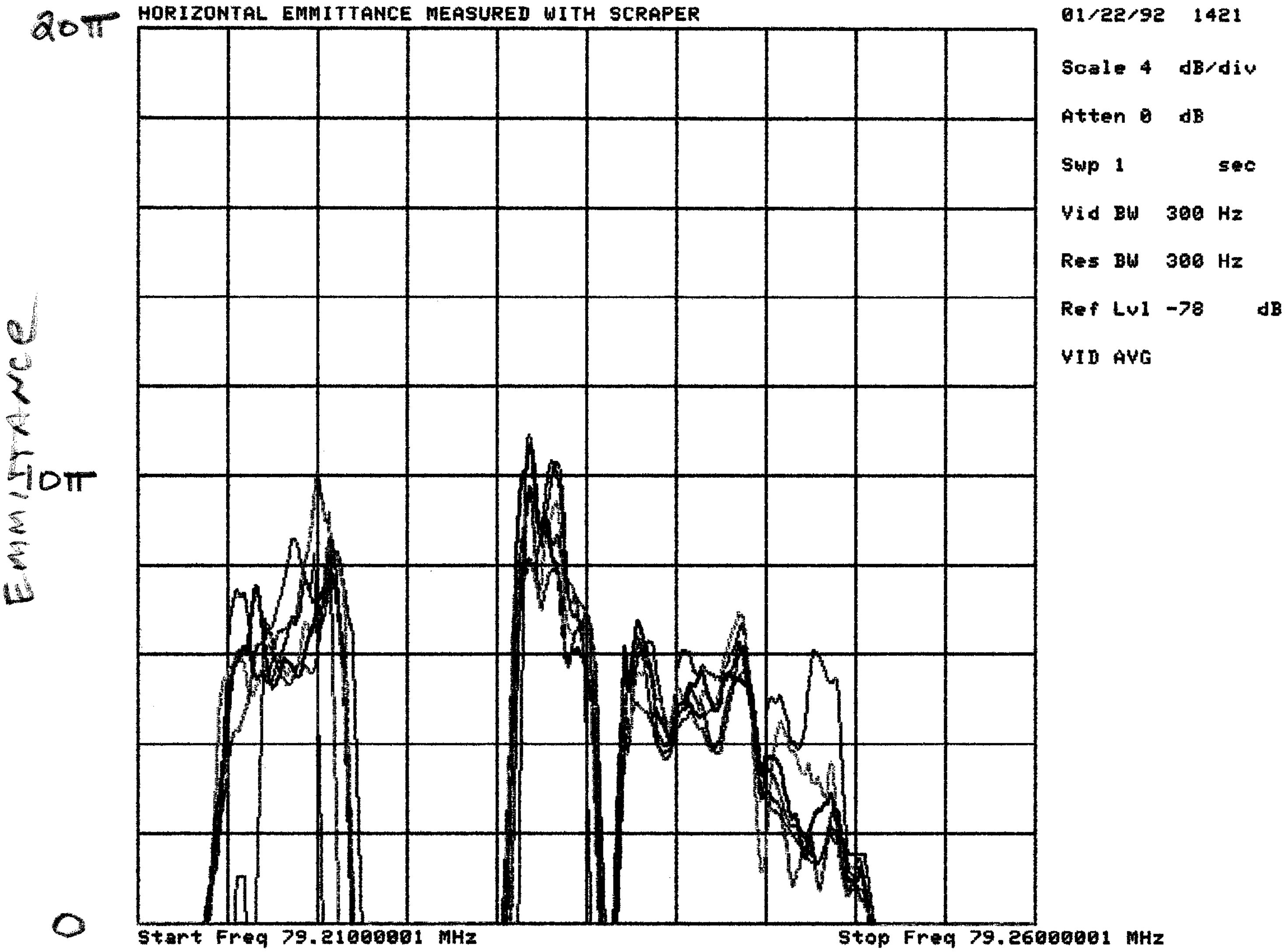


Figure 3

CONSOLE LOCATION 43, 22-JAN-1992 15:53
Pbar SA Plot

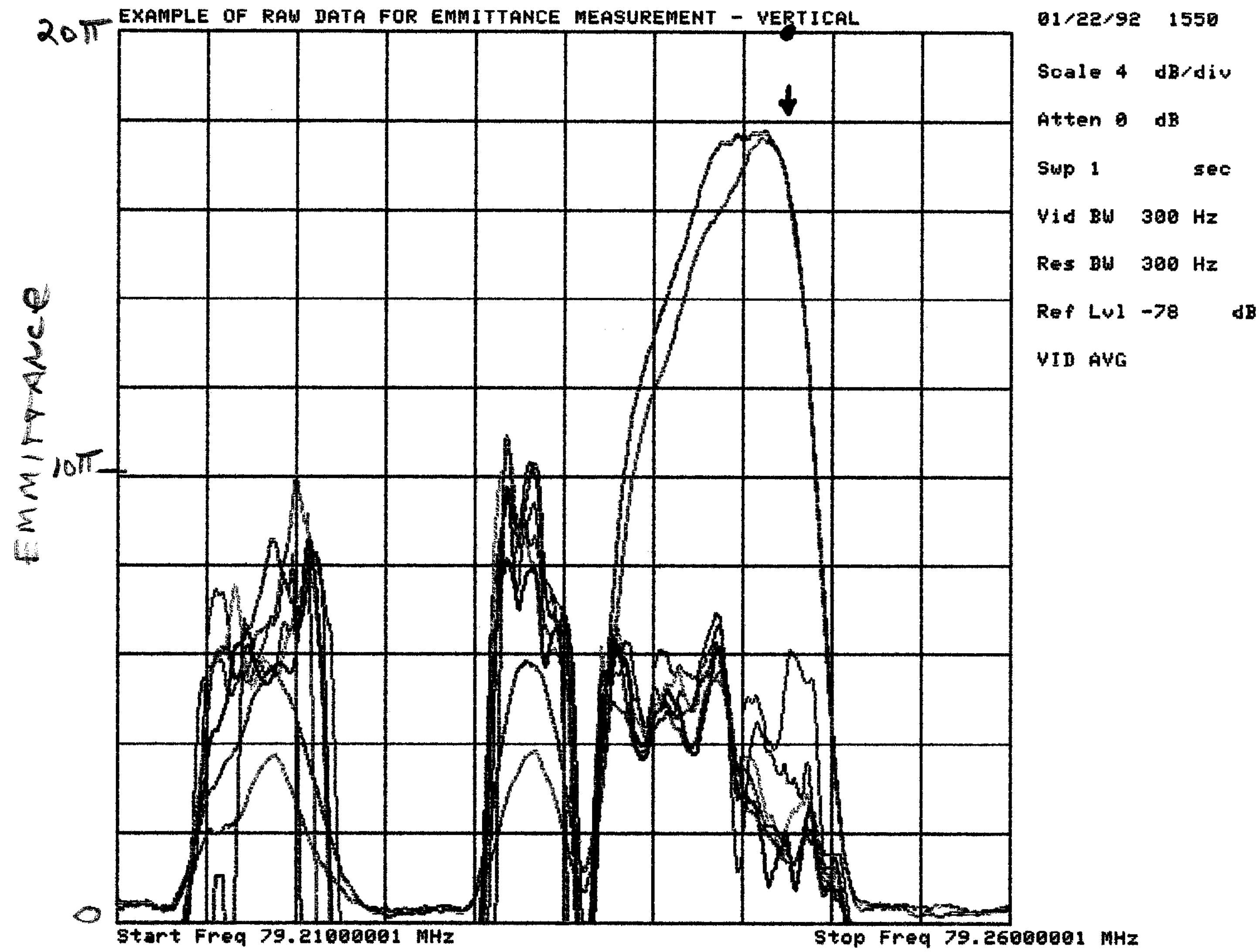


FIGURE 4

CONSOLE LOCATION 43, 22-JAN-1992 14:33
Pbar SA Plot

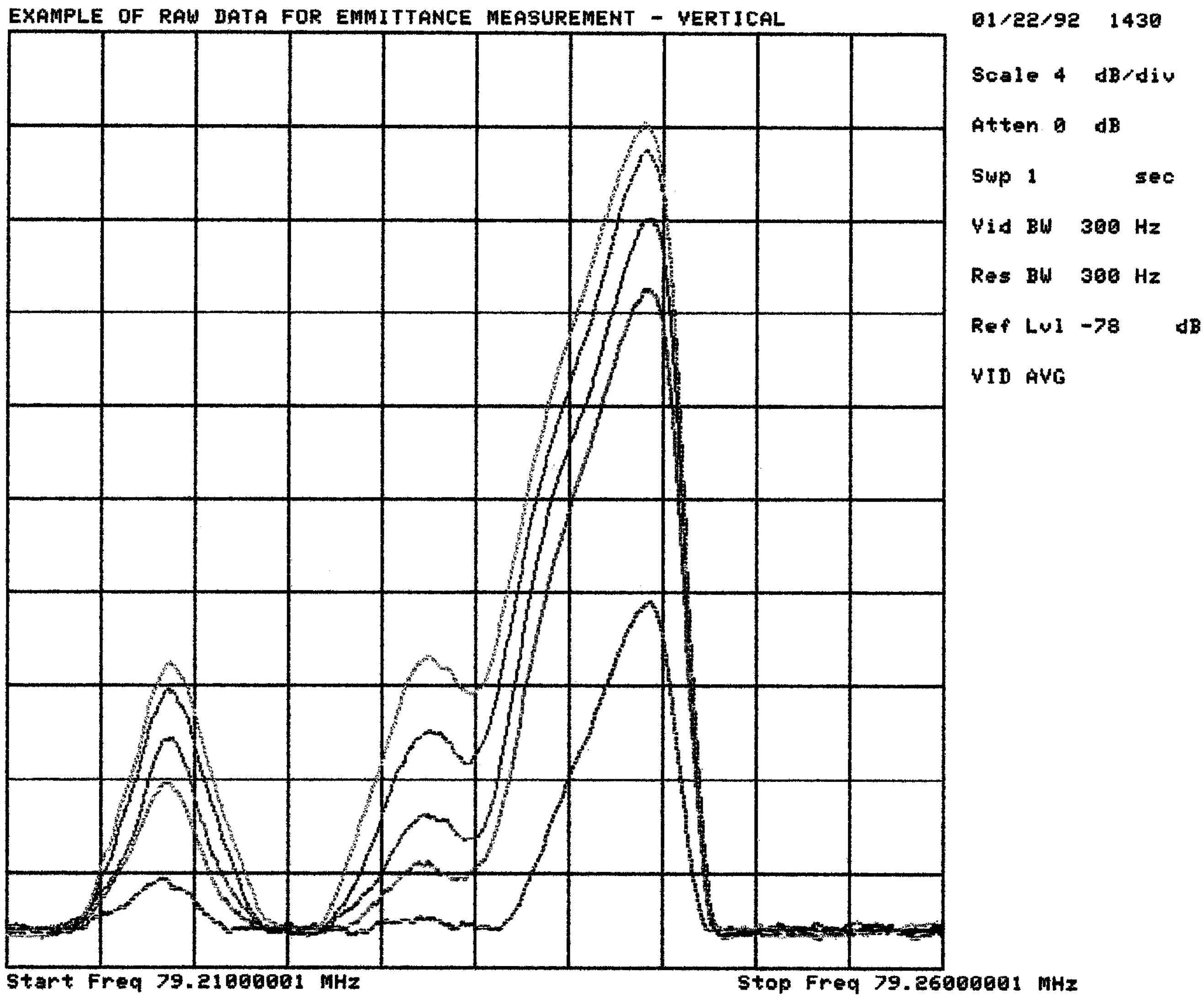


Figure 5

CONSOLE LOCATION 43, 22-JAN-1992 16:02
Pbar SA Plot

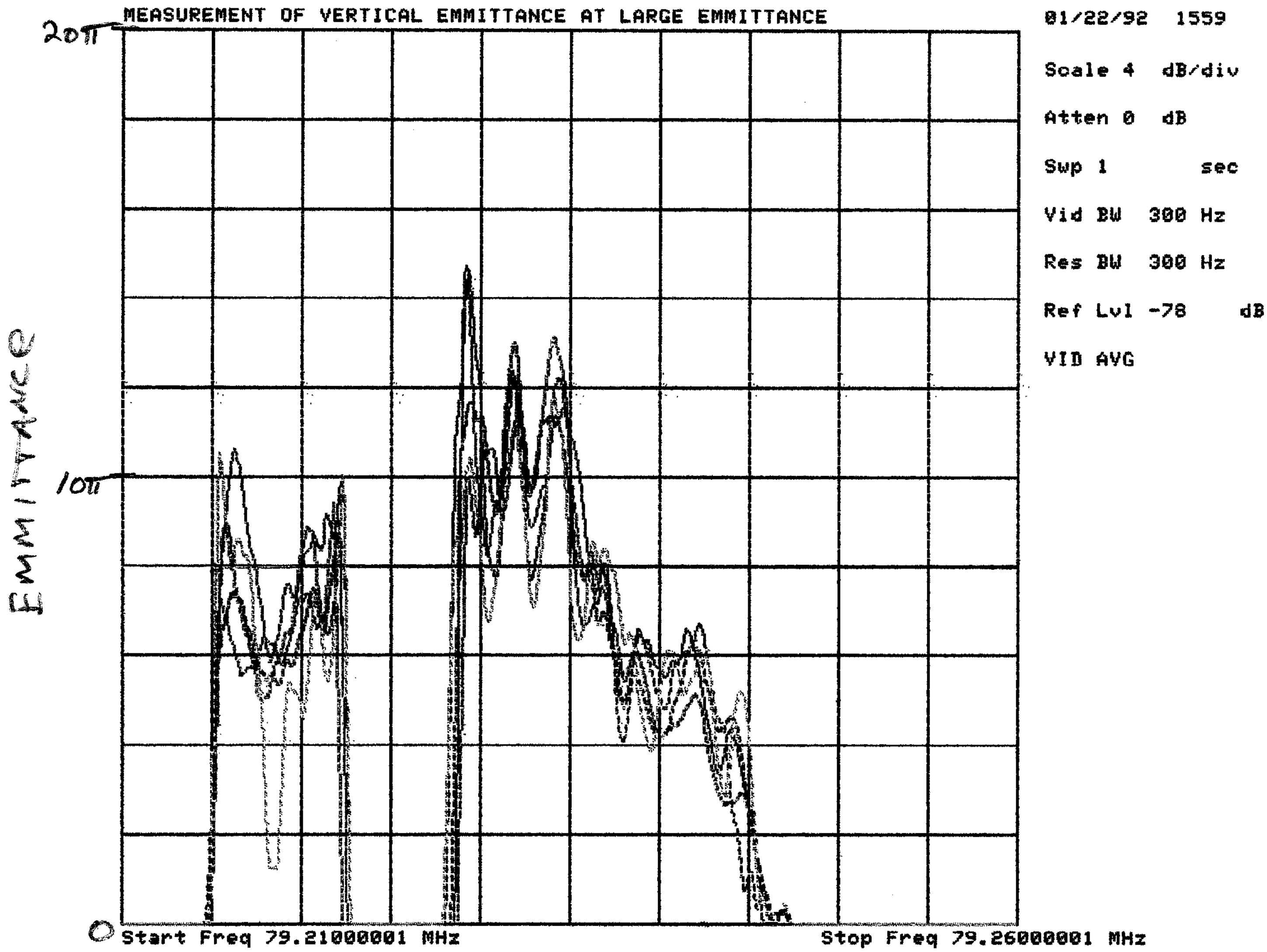
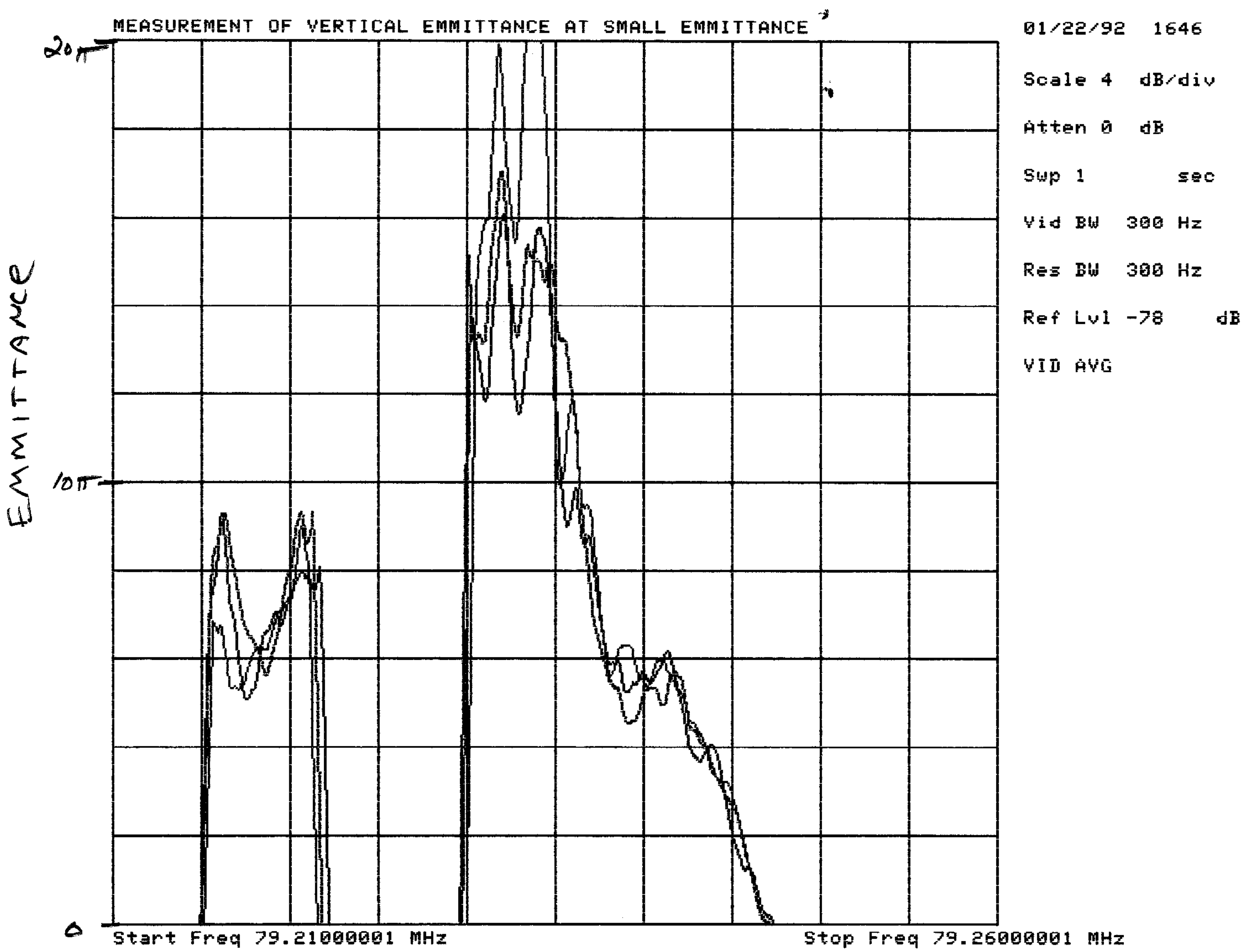
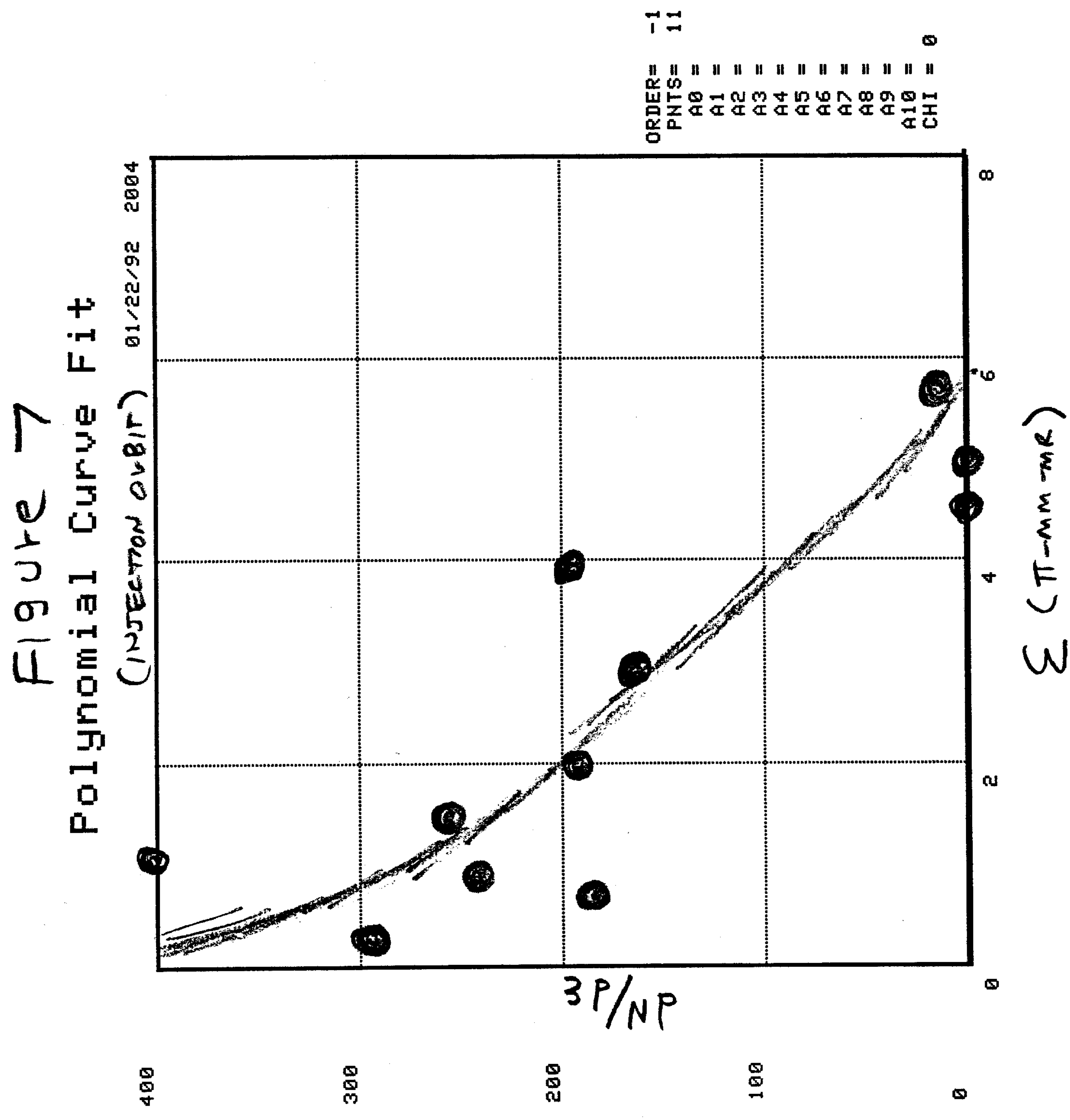


Figure 6

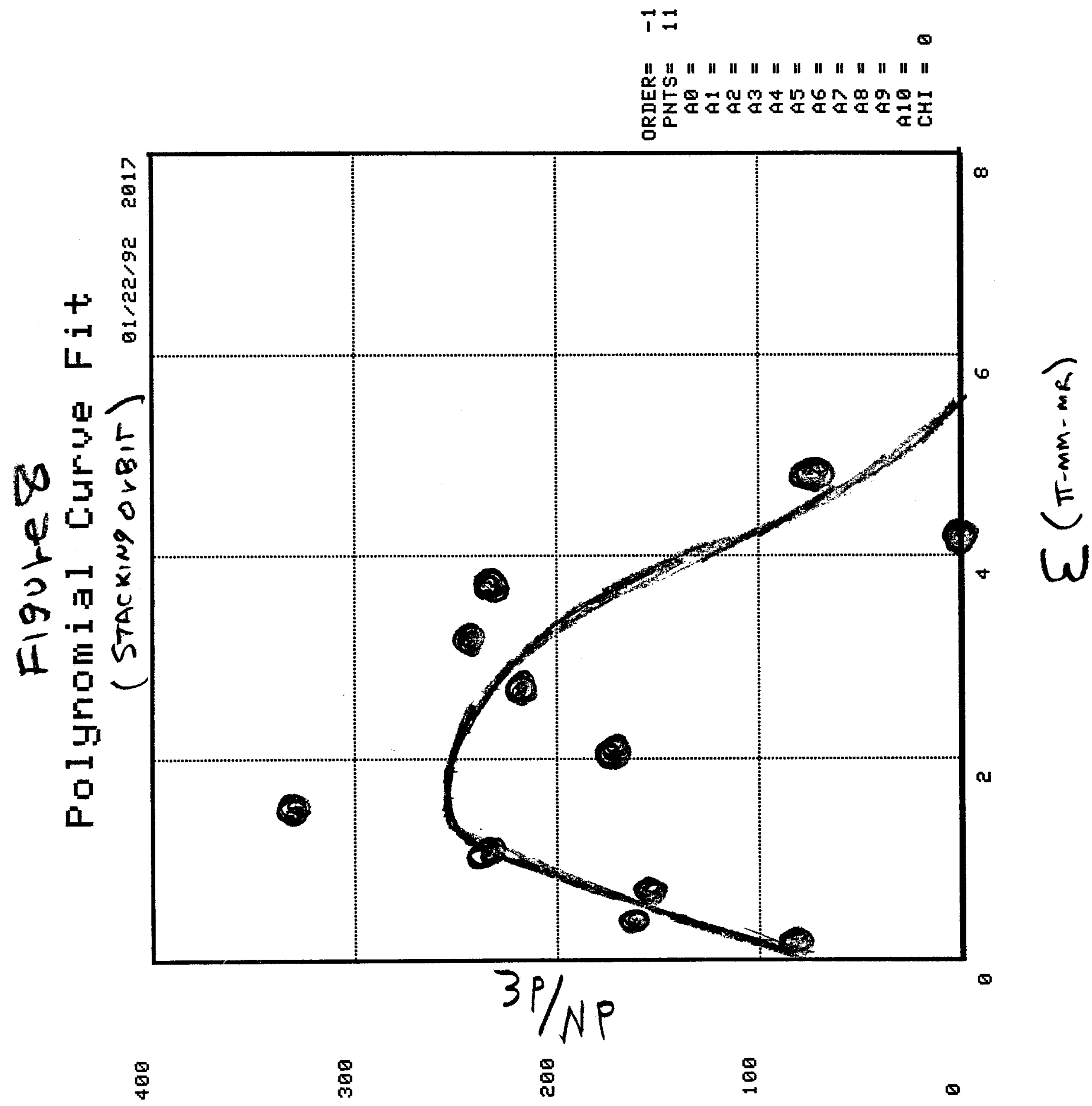
CONSOLE LOCATION 43,   22-JAN-1992 16:49
Pbar SA Plot



CONSOLE LOCATION 43;   22-JAN-1992 20:06
Curve fitter II



CONSOLE LOCATION 43;   22-JAN-1992 20:19
Curve fitter II



Log 18, P19 1/13/92 Figure 9

.3 mA beam

		MADC volts	volts	Lecroy p-p	f
(10)	$\frac{53.25}{4} = 13.3$	-9.01	951	2.990	2.36010086
(11)	$\frac{72.50}{6} = 12.1$	-7.65	807	2.545	
(12)	$\frac{64.75}{6} = 10.8$	-6.21	654	2.090	
(13)	$\frac{54.25}{6} = 9.04$	-4.45	465	1.505	
(14)	$\frac{70.25}{10} = 7.02$	-2.45	250	0.840	
(15)	No signal	-8.975	951	2.980	2.360159 (center)

E schottky # = 128

See hardcopy log for synchrotron frequency plots
Data will be analyzed later.

06:00 Measurement of tunes across Acc aperture:
see hardcopy log

f_0	Q_H	Q_V
.628724	.614	.606
.628785	.625	.601
.628846	.614	.607
.628901	.618	.607
.628956	.615	.611

can't tell which is which (coupling)
how about these resonances, eh?

06:40 Measure transverse accumulator aperture on the injection orbit. Close shutter when injecting to keep beam out of core and center.

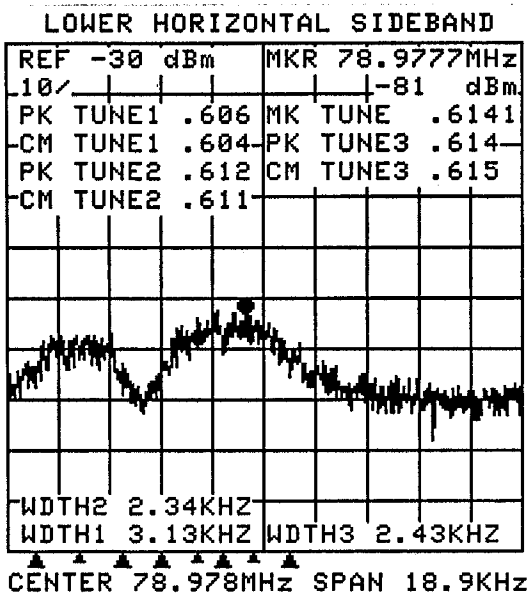
$A_H = 8.6\pi$, $A_V = 8.1\pi$

See hardcopy log

08:00 End of reverse proton studies.

Figure 10

CONSOLE LOCATION 15; AP10 13-JAN-1992 06:10

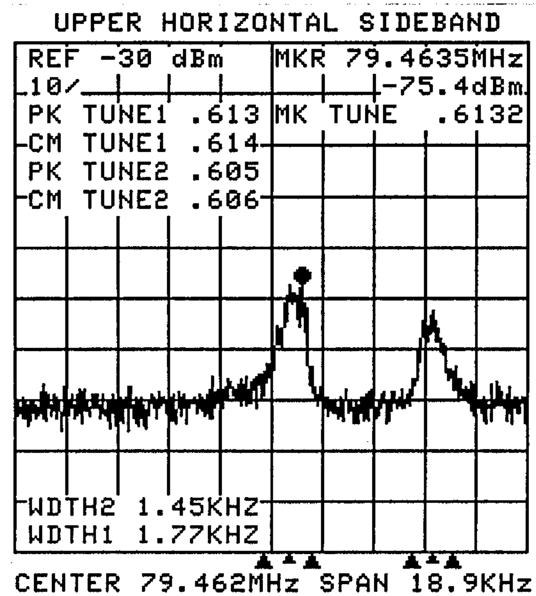


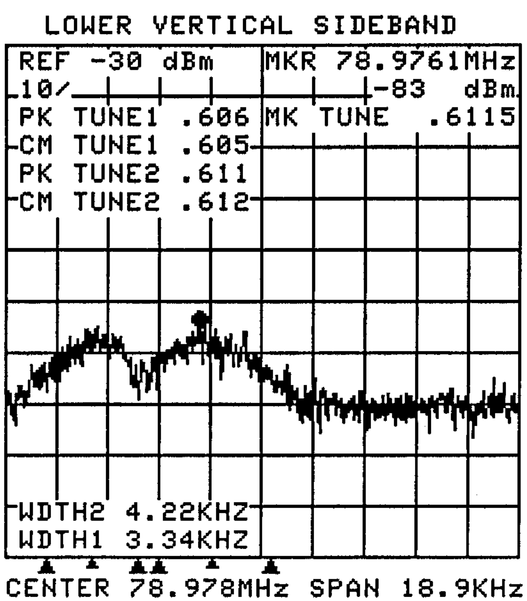
ACCUMULATOR

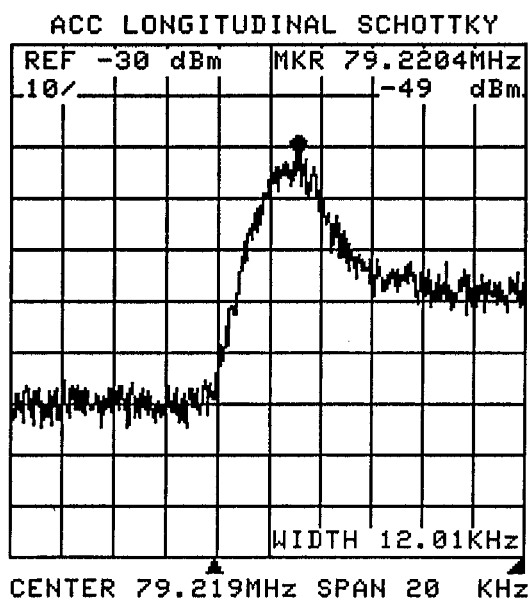
01/13/92 0610

BEAM CURRENT	2.107	mA
HARMONIC NUMBER	126	
REV FREQUENCY	628733	Hz
DELTAP/P	.659	%
HORIZONTAL TUNE	.6132	
VERTICAL TUNE	.6134	
HORZ EMITTANCE	1.959	
VERT EMITTANCE	1.759	
HORZ CHROMATICITY	.4554	
VERT CHROMATICITY	1.555	

@ .628724 injection







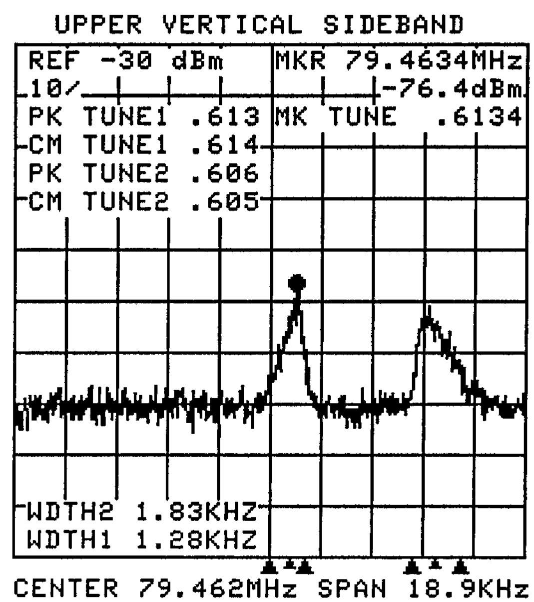
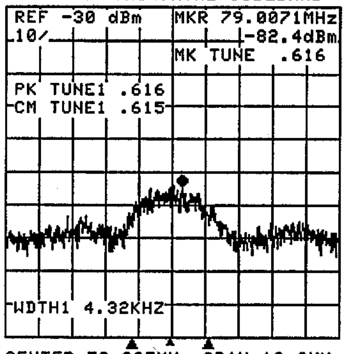


Figure H

LOWER HORIZONTAL SIDEBAND



CENTER 79.007MHz SPAN 18.9KHz

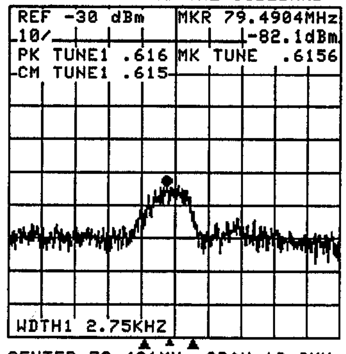
ACCUMULATOR

01/13/92 0632

BEAM CURRENT	1.268 mA
HARMONIC NUMBER	126
REV FREQUENCY	628958 Hz
DELTAP/P	.2916 %
HORIZONTAL TUNE	.6156
VERTICAL TUNE	.6112
HORZ EMITTANCE	.7782
VERT EMITTANCE	.4593
HORZ CHROMATICITY	.6425

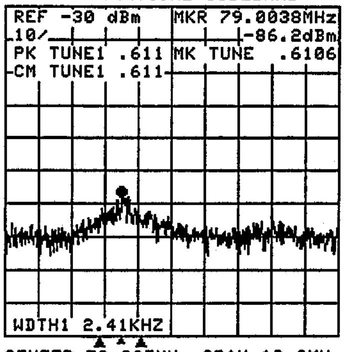
@ 628956 core

UPPER HORIZONTAL SIDEBAND



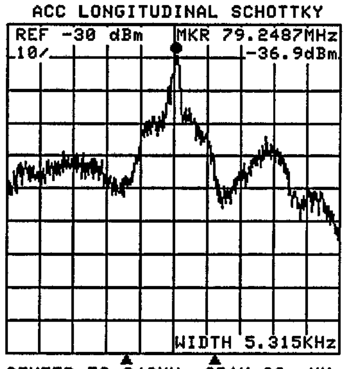
CENTER 79.491MHz SPAN 18.9KHz

LOWER VERTICAL SIDEBAND



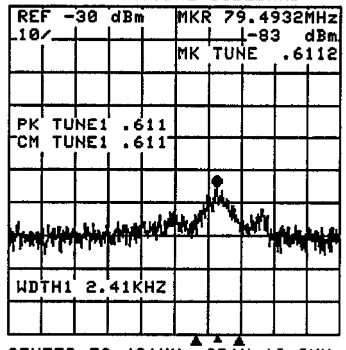
CENTER 79.007MHz SPAN 18.9KHz

ACC LONGITUDINAL SCHOTTKY



CENTER 79.249MHz SPAN 20 KHz

UPPER VERTICAL SIDEBAND



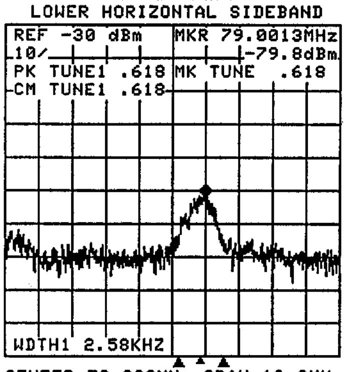
CENTER 79.491MHz SPAN 18.9KHz

CONSOLE LOCATION 15; AP10

13-JAN-1992 06:32

8

LOWER HORIZONTAL SIDEBAND



CENTER 78.999MHz SPAN 18.9KHz.

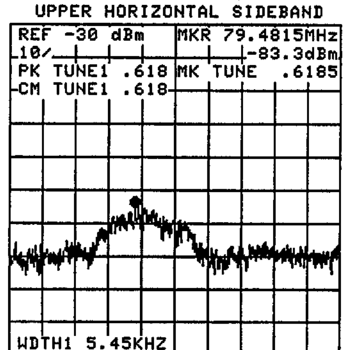
ACCUMULATOR

01/13/92 0627

BEAM CURRENT	1.269 mA
HARMONIC NUMBER	126
REV FREQUENCY	628901 Hz
DELTAP/P	.2631 %
HORIZONTAL TUNE	.6185
VERTICAL TUNE	.6072
HORZ EMITTANCE	.7969
VERT EMITTANCE	.4605
HORZ CHROMATICITY	-1.031
VERT CHROMATICITY	2.921

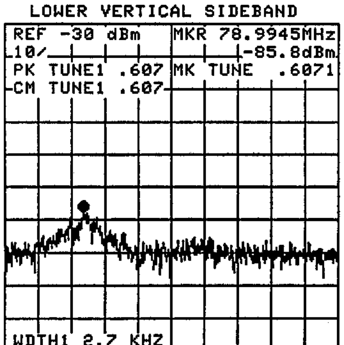
@ .628901

UPPER HORIZONTAL SIDEBAND



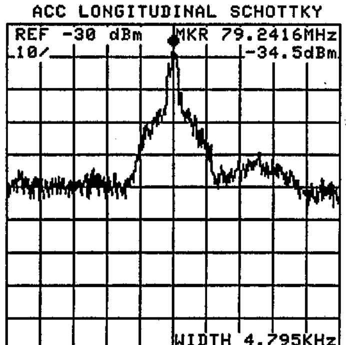
CENTER 79.484MHz SPAN 18.9KHz

LOWER VERTICAL SIDEBAND



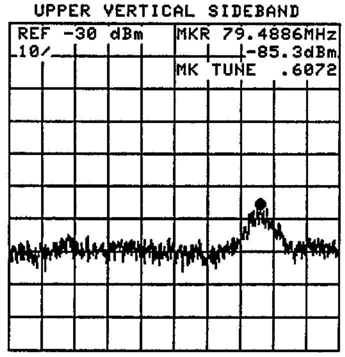
CENTER 78.999MHz SPAN 18.9KHz

ACC LONGITUDINAL SCHOTTKY



CENTER 79.242MHz SPAN 20 KHz

UPPER VERTICAL SIDEBAND



CENTER 79.484MHz SPAN 18.9KHz

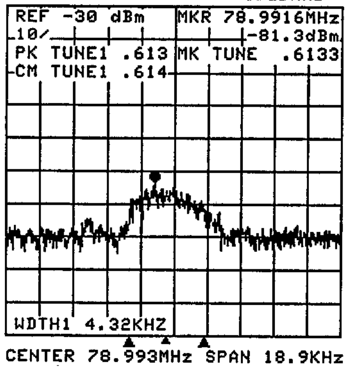
CONSOLE LOCATION 15; AP10

13-JAN-1992 06:28

Figure-12

CONSOLE LOCATION 15; AP10 13-JAN-1992 06:23

LOWER HORIZONTAL SIDEBAND



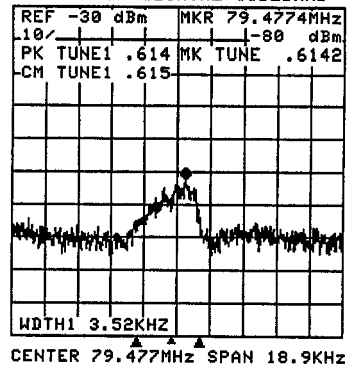
ACCUMULATOR

01/13/92 0622

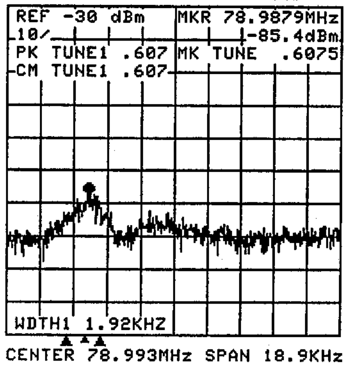
BEAM CURRENT	1.271 mA
HARMONIC NUMBER	126
REV FREQUENCY	628847 Hz
DELTAP/P	.2335 %
HORIZONTAL TUNE	.6142
VERTICAL TUNE	.6072
HORZ EMITTANCE	.9594
VERT EMITTANCE	.4871
HORZ CHROMATICITY	.2928
VERT CHROMATICITY	.2806

@ 628846 center

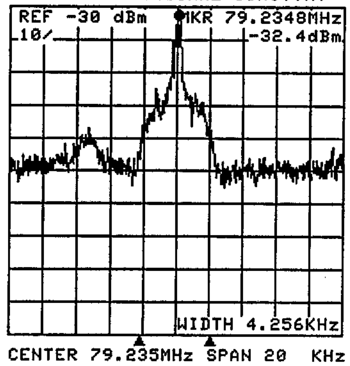
UPPER HORIZONTAL SIDEBAND



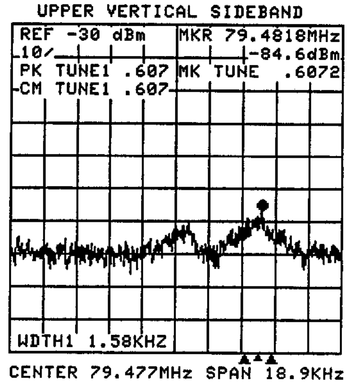
LOWER VERTICAL SIDEBAND



ACC LONGITUDINAL SCHOTTKY

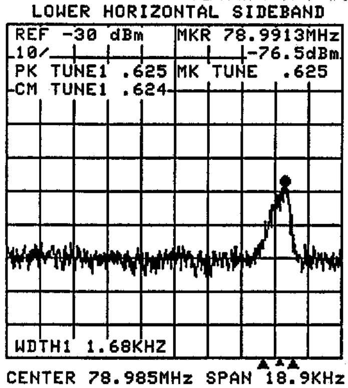


UPPER VERTICAL SIDEBAND



CONSOLE LOCATION 15; AP10 13-JAN-1992 06:17

LOWER HORIZONTAL SIDEBAND



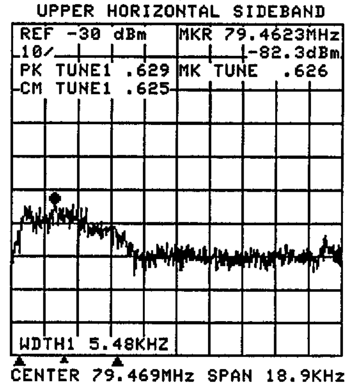
ACCUMULATOR

01/13/92 0617

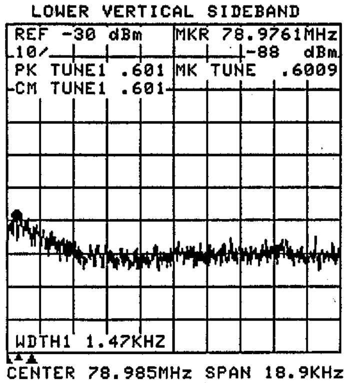
BEAM CURRENT	1.3 mA
HARMONIC NUMBER	126
REV FREQUENCY	628786 Hz
DELTAP/P	.216 %
HORIZONTAL TUNE	.626
VERTICAL TUNE	.6014
HORZ EMITTANCE	.8272
VERT EMITTANCE	.7714
HORZ CHROMATICITY	-1.534
VERT CHROMATICITY	2.921

f_o = .628785

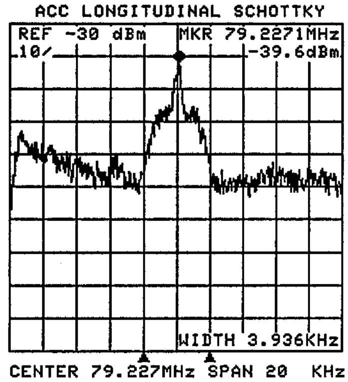
UPPER HORIZONTAL SIDEBAND



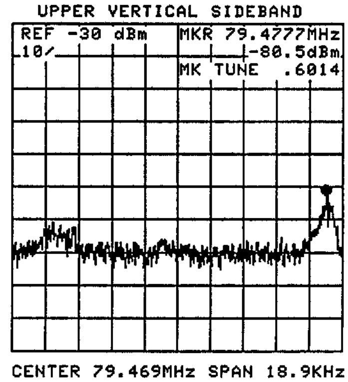
LOWER VERTICAL SIDEBAND



ACC LONGITUDINAL SCHOTTKY



UPPER VERTICAL SIDEBAND



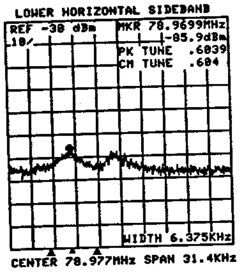
Log 17, P190 Figure 13

190

FINAL TUNES.

"Real" Injection

LOWER HORIZONTAL SIDEBAND



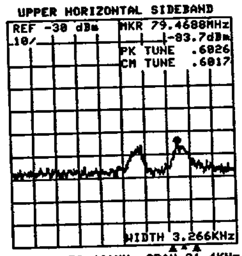
CENTER 78.977MHz SPAN 31.4KHz

ACCUMULATOR

07/02/91 1717

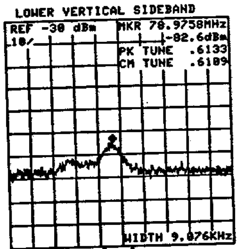
BEAM CURRENT	1.718 mA
HARMONIC NUMBER	126
REV FREQUENCY	628722 Hz
DELTAP/P	.4847 %
HORIZONTAL TUNE	.604
VERTICAL TUNE	.6109
HORZ EMITTANCE	.218
VERT EMITTANCE	.3077
HORZ CHROMATICITY	.9369
VERT CHROMATICITY	1.056

UPPER HORIZONTAL SIDEBAND



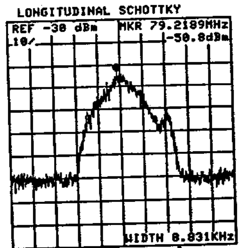
CENTER 79.461MHz SPAN 31.4KHz

LOWER VERTICAL SIDEBAND



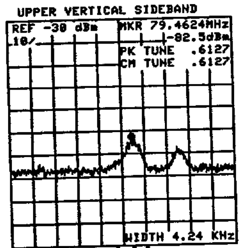
CENTER 78.977MHz SPAN 31.4KHz

LONGITUDINAL SCHOTTKY



CENTER 79.219MHz SPAN 20 KHz

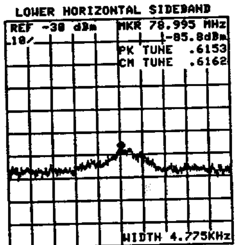
UPPER VERTICAL SIDEBAND



CENTER 79.461MHz SPAN 31.4KHz

Central

LOWER HORIZONTAL SIDEBAND



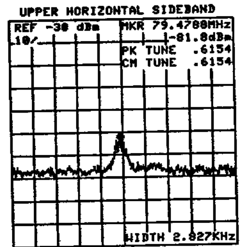
CENTER 78.995MHz SPAN 31.4KHz

ACCUMULATOR

07/02/91 1722

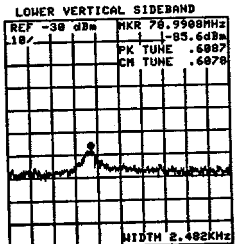
BEAM CURRENT	1.35 mA
HARMONIC NUMBER	126
REV FREQUENCY	628864 Hz
DELTAP/P	.7795 %
HORIZONTAL TUNE	.6162
VERTICAL TUNE	.6078
HORZ EMITTANCE	.4147
VERT EMITTANCE	.1513
HORZ CHROMATICITY	.7439
VERT CHROMATICITY	-.106

UPPER HORIZONTAL SIDEBAND



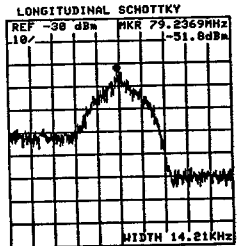
CENTER 79.479MHz SPAN 31.4KHz

LOWER VERTICAL SIDEBAND



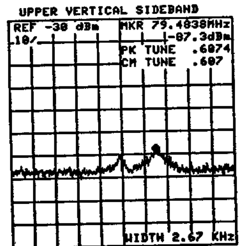
CENTER 78.995MHz SPAN 31.4KHz

LONGITUDINAL SCHOTTKY



CENTER 79.237MHz SPAN 20 KHz

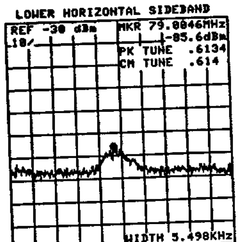
UPPER VERTICAL SIDEBAND



CENTER 79.479MHz SPAN 31.4KHz

Core

LOWER HORIZONTAL SIDEBAND



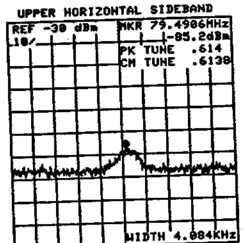
CENTER 79.006MHz SPAN 31.4KHz

ACCUMULATOR

07/02/91 1725

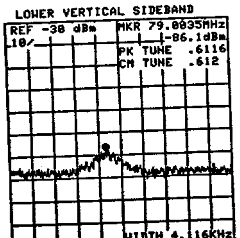
BEAM CURRENT	1.349 mA
HARMONIC NUMBER	126
REV FREQUENCY	628951 Hz
DELTAP/P	.3574 %
HORIZONTAL TUNE	.614
VERTICAL TUNE	.612
HORZ EMITTANCE	.1724
VERT EMITTANCE	.2092
HORZ CHROMATICITY	.428
VERT CHROMATICITY	.2267

UPPER HORIZONTAL SIDEBAND



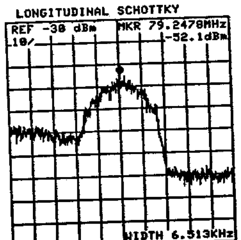
CENTER 79.49 MHz SPAN 31.4KHz

LOWER VERTICAL SIDEBAND



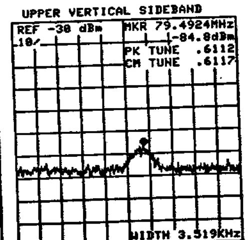
CENTER 79.006MHz SPAN 31.4KHz

LONGITUDINAL SCHOTTKY



CENTER 79.248MHz SPAN 20 KHz

UPPER VERTICAL SIDEBAND

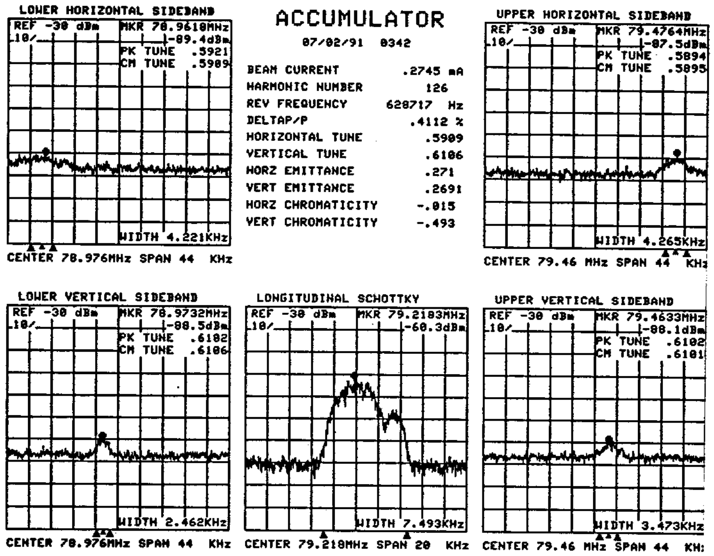


CENTER 79.49 MHz SPAN 31.4KHz

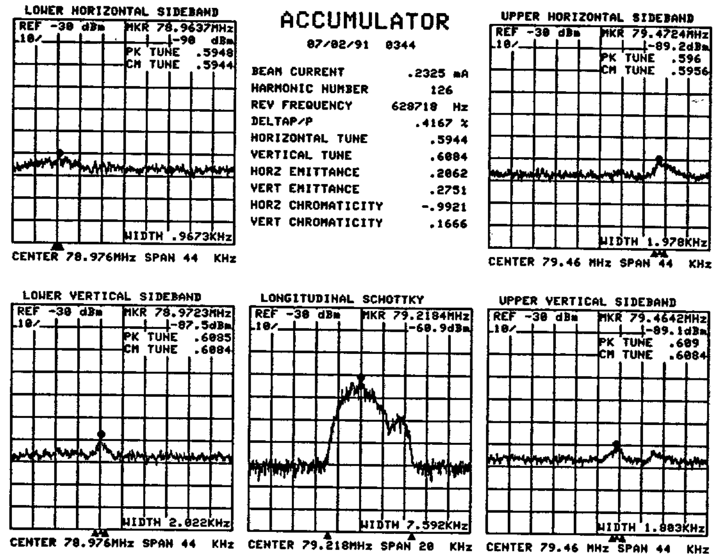
LOG 17, P181 Figure 1A

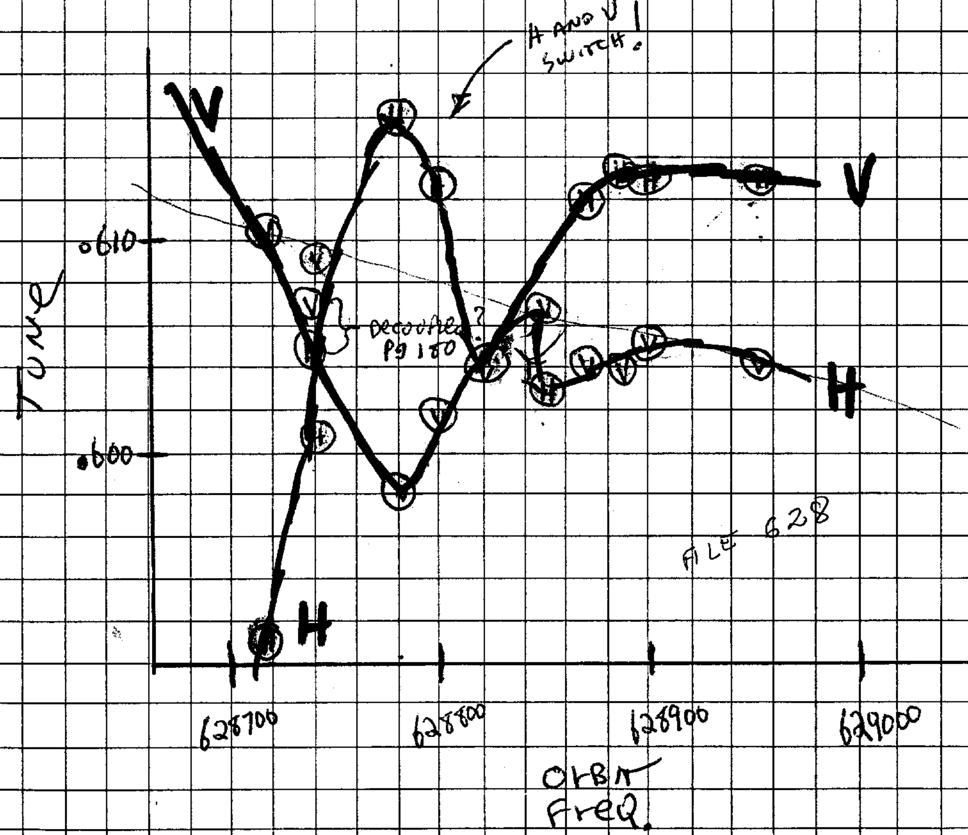
TUNES AT THE REAL "INJECTION" MOMENTUM

D:ELAM ON



D: ELAM OFF





TUNES VERSUS MOMENTUM

SEE H.C. FOR PLOTS.

NO CHROMATICITY CORRECTION WILL FIX THIS — IS THE NEW OCTUPOLE MAGNET WIRED RIGHT?